INSTITUTE OF HIGH ENERGY PHYSICS, SERPUKHOV

Report IFVE SPK 71-92

ON THE PROBLEM OF IMPROVING A CRT UNIT WITH HIGH RESOLUTION FOR SCANNING AUTOMATIC UNITS

B.A. Utochkin and B.M. Rabin

Serpukhov 1971

Translated at CERN by R. Luther
(Original: Russian)
Not revised by the Translation Service

(CERN Trans. 72-18)

Geneva
September 1972

Automatic scanning and measuring units incorporating cathode-ray tubes (CRT) are nowadays one of the most promising types of precision instrument used for processing track chamber pictures at a fast rate/1/. A high-resolution precision CRT is used to generate the light spot in these devices. The capability and main characteristics of the automatic unit depend on the capability and characteristics of the CRT. This report examines the general aspects of two new methods for improving the characteristics and reliability of a high-resolution CRT.

1. A CRT with "high-voltage compression" of the cathode ray in the space between the main focussing lens and the screen.

Before considering the special features of the new CRT, a brief summary is required of the shortcomings and problems encountered with conventional high-resolution CRT units.

The left-hand part of Fig. I includes a diagram of a CRT unit with the set of magnet control elements which are normally used in conventional automatic units incorporating a CRT. The names of the elements are given in the key to Fig. 1. The set of subsidiary elements (alignment coil and centring coils) has been omitted. Any type of electron gun is used. For tetrode guns, "C" marks the position of the second crossover.

The diameter of the light spot in the centre of the CRT screen is determined by the diameter of the electron gun's crossover, by the magnification and aberrations of the main focussing lens, and also by the properties and structure of the screen's fluorescent coating. The useful luminous flux from the screen is directly proportional to the beam current and the energy with which the electrons excite the phosphor coating provided there is no saturation effect.

As the light spot is deflected across the tube's useful field, it increases in size, its shape is distorted and the amount of deflection is soon no longer directly proportional to the value of the deflecting magnetic field. As shown in /2/, if there are no second-order aberrations, third-order aberrations Δx and Δy contain the sum of the terms forming the product

$$\Sum A_i \cdot \omega^n \cdot \mathrm{tg}^m \alpha, \qquad (1)$$

where A_i are the aberration factors determined by the properties of the deflection yoke and its position on the CRT (the other symbols in the formula are shown in Fig. 1).

For astigmatism and field curvature $n = 1$, $m = 2$, for coma $n = 2$, $m = 1$ and for pin-cushion distortion $n = 0$, $m = 3$.

It follows from expression (1) that it is essential to try to minimize the angle of deflection α and the angle of convergence ω in order to reduce deflection aberrations. However, in a conventional high-resolution CRT, all these values are already optimized and, in order to compensate the above aberrations, a complicated system of dynamic corrections to field curvature (focussing) and astigmatism is used which requires special electronic circuits/3/. Deflection distortion is lessened by means of an octupole lens. There is a strong interaction between the many magnetic control elements with metal cores and bodies which are arranged along the optical axis of the CRT bulb.

This gives rise to many difficulties from dynamic effects at precision levels (effect of eddy currents, hysteresis phenomena etc.).

In certain special types of automatic CRT measuring equipment, for instance in the analog analyzer of bubble chamber pictures/4/, dynamic corrections for deflection aberrations are generally difficult to make and hamper the reliable operation of the device.

We were assigned and solved the task of reducing the effect of deflection aberrations by re-designing a conventional CRT system and reducing the angles of deflection and convergence without changing the size of the spot, the useful field on the screen and the useful luminous flux.

A schematic layout of the new high-resolution CRT is shown in the right-hand part of Fig. 1. The main focussing lens FC_1 projects an image of the crossover C on to the screen as in a conventional tube. However, in the space between this lens and the screen, the normal drift region at crossover potential has been replaced by a longitudinal accelerating field with a specific law for the distribution of the gradient value along the optical axis.

The deflection length L_1 was thus increased considerably (viz. Fig. 1b) and the angle of convergence ω reduced, but, due to the "high-voltage compression" of the electron beam, the diameter of the light spot was kept constant in the centre of the screen and varied only very slightly during deflection throughout the useful field. This compression was derived from the Helmholtz equation for the relativistic case

$$x_0 \omega_0 \Phi_0(z) / p_0(z) = x \, \omega \, \Phi(z) / p(z) , \qquad (2)$$

where x_0 is the electron beam's cross-section at crossover, ω_0 is the electron beam's angle of divergence at the crossover, x is the beam's cross-section in the screen's plane, ω is the electrons' angle of convergence at the screen, Φ_0 and Φ are the accelerating potentials and p_0 and p the momenta of the electrons at crossover and at the screen respectively as a function of the longitudinal coordinate (p = mv, m is the mass and v the velocity of the electron).

For conventional tubes, where the electron energy in the section between the crossover and the screen does not vary, expression (2) has a simplified form (same notation)

$$x_0 \, \omega_0 = x \, \omega = \text{const} \qquad (3)$$

and it may be conveniently represented in the phase plane (viz. ellipse "a" in Fig. 2). Depending on the geometry of the optical system, i.e. on the position of the main focussing lens, it is possible to use either x or ω but the area of the ellipse must remain the same.

In the case of the new tube, where the energy and momentum of the electrons steadily increase as they move towards the screen, the area of the ellipse shrinks and has a finite value at the screen (viz. hatched ellipse in Fig. 2). The concept of "high-voltage compression" may also be applied to the shrinking of this area.

The geometry of the optical system for the new tube was selected so that the electrons' angle of convergence could be reduced as much as possible without changing the cross-section of the beam on the screen (viz. ellipse "δ" in Fig. 2). Although the length $b_1 > a_1$, the magnification remains approximately the same as for a conventional tube and now depends not only on the geometry of the system but also on the gradient of the longitudinal accelerating field.

By increasing the energy of the electrons at the screen, the beam current was reduced due to the greater diaphragming of the beam in the gun. This led to a further reduction in the angle of convergence (viz. Fig. 1d) and did not affect the useful luminous flux from the screen.

It should also be pointed out that the cross-section of the electron beam in the plane of the main focussing lens was substantially reduced: $d_1^* < d_1 < d$ (viz. Figs. 1c and 1d). This led to a considerable reduction in the contribution of spherical aberration from this lens, which is, of course, proportional to the cube of the beam's cross-section.

By increasing the length between the focussing lens and the screen, the angle of deflection was reduced whilst still maintaining quite a large gap between DY_1 and [illegible], which is crucial for improving the dynamic processes in the CRT. The reduction in the angle of deflection almost compensated the drop in deflection efficiency caused by the increase in electron energy in the deflection region.

Thus, by redesigning the optical system, the angles of convergence and deflection are considerably reduced whilst retaining the other main characteristics. Taking into account the strong non-linear dependence of deflection aberrations on these angles, it may be stated that it is no longer necessary to make dynamic corrections to these aberrations when operating at the limit of the fixed useful field. If the useful field has to be increased then the necessary corrections can be made by means of extremely simple methods and equipment.

A full analysis of the processes in the new tube will be given in a separate report. It should be pointed out that allowance must be made for the relativistic effect when constructing the tube, as the mass of the electrons increases by 5 - 6%. This must be taken into consideration for precision tubes.

To end this section, we shall give a few data obtained from test samples of the new tube with screen diameters of 130 and 180 mm and a maximum length for both tubes of 650 mm.

The tube with the 130 mm screen was fitted to a CRT module to be used in a model of an automatic scanning unit designed to process bubble chamber pictures. It included a specially designed deflecting system and focussing coil. A light spot 24 - 26 μm in diameter within 0.6 of maximum intensity was obtained on the [illegible] effective field without dynamic corrections. The energy of the electrons at crossover was 12 keV and the energy at the screen was 32 keV. The longitudinal accelerating field was set up by means of a high-impedance resistance helix mounted on the inner surface of the bulb with a fixed gradient and law for its dependence on the longitudinal coordinate.

According to preliminary estimates, pin-cushion distortion of the deflection on the above screen did not exceed 0.5%. Geometrical distortions of this type were reduced because the natural distortion of the electrostatic lens formed by the accelerating helix is barrel-shaped/5/.

The new tubes are designed so that, despite the presence of high voltages, high-voltage arcing is possible neither in the gun nor in the individual components connected to earth.

The cut-off voltage is still the same as in conventional tubes - 60 V.

II. CRT with a low-voltage gun producing a "quasi-laminar" cathode ray.

Reports have appeared recently about the development of cathode-ray tubes with a new type of gun which produces a cathode ray with quasi-laminar properties/6,7,8/. The schematic layout of a version of this type of gun is shown in Fig. 3. A set of flat plates is placed alongside and strictly parallel to the flat top of the cathode. The distances between the plates and the cathode, the diameter of the apertures, the thickness of the plates and the potentials on them were all selected so that electrons emitted from the surface of the cathode would produce a flux without forming a crossover. The last plate, in front of which the electron flux is strongly collimated, faces the screen. The configuration of the field must be designed to reduce the tangential components of the electron's velocity so that a virtually parallel beam is produced.

The CRT anode may be either a conventional cylindrical [illegible] with a conducting coating or else an accelerating resistance helix may be placed in the section in front of the screen. The maximum gun potential does not exceed 0.5 - 2 kV. Up to 15-30 kV may be passed to the high-voltage end of the accelerating helix (screen potential).

The thickness of the plates is also an important feature of the new gun. The first accelerating plate is very thin and is placed directly in front of the surface of the cathode, the second plate acts both as an accelerator and as a screening electrode as the diameter of its aperture is one half of its thickness; the field in the next electrode, which is subjected to a higher potential, does not penetrate the cathode region. The beam current is modulated by varying the potential on the second screening plate The beam is collimated quite noticeably and the beam current at the aperture of the last plate (0.01 inch) may reach 50 - 100 µA. The beam's angle of divergence decreases as the current increases. The reasons for this phenomenon have still not been sufficiently investigated.

The advantage of the new gun is that it operates at potentials considerably below the level at which internal arcing and cold emission from the electrodes normally occur. The maximum load on the cathode is lower than in conventional tubes so that its life-time must be increased. At the above beam current values, the screen's fluorescent coating is excited to a high intensity and the light spot is correspondingly bright. The distribution of brightness in a spot of 25 µm in diameter is almost uniform and not Gaussian as in conventional tubes. This is due to the quasi-laminar property of the cathode ray which produces a uniform electron density distribution across the ray's cross-section in the screen plane. The shape of the spot on the screen is an accurate image of the gun's aperture, so that a spot of any shape may be produced. The size of the spot remains constant despite the considerable range of variation of the voltage on the control cathode.

One very valuable asset of the new gun is that when several apertures (with parallel optical axes) are placed side by side in the plates , several identical light spots may be formed. A series of interesting new algorithms may thus be applied to the operation of automatic CRT scanning units and other similar systems.

Fig. 4 shows a possible circuit for a CRT unit and the new electron gun. It is obvious that the tube is considerably shorter than conventional tubes. Most of the conventional control elements except for the deflection yoke and the octupole lens for distortion correction are missing. A gun with electrostatic "focussing" produces such a small beam cross-section in the deflection region that virtually no dynamic corrections to focussing and astigmatism are required when the spot is deflected through the useful field.

BIBLIOGRAPHY

1. R. Barr et al. Devices for scientific research No. 10, 144, 1969.
2. B.E. Bonshtedt, M.G. Markovich. Fokusirovka i otklonenie elektronnykh puchkov. M., "Sov. Radio", 1967.
3. N.I. Berlin, A.A. Gorelov, B.M. Kats, M.G. Markovich, E.K. Ovchinnikov, I.I. Tsykkerman. Tekhnika kino i televideniya, No. 3, 43, 1970.
4. S.N. Sokolov, B.A. Utochkin. IHEP Preprint 70-76, Serpukhov, 1970.
5. V.P. Kartashev, B.A. Utochkin. Radiotekhnika i elektronika, No. 6, t. XII, 1967, p.1132.
6. English patent, cl. N.1, No. 1119931, applied for 16.07.65, issued 17.07.68.
7. New Concept in Electron Gun Design. Industrial Electronics, 5, No. 11, 493, 1967.
8. New Electron Gun Developed for Cathode-ray Tube. Electronic Technician Dealer, No. 4, vol. 88, 108, 1968.

The document was received by the publishing group on 28 September 1971.

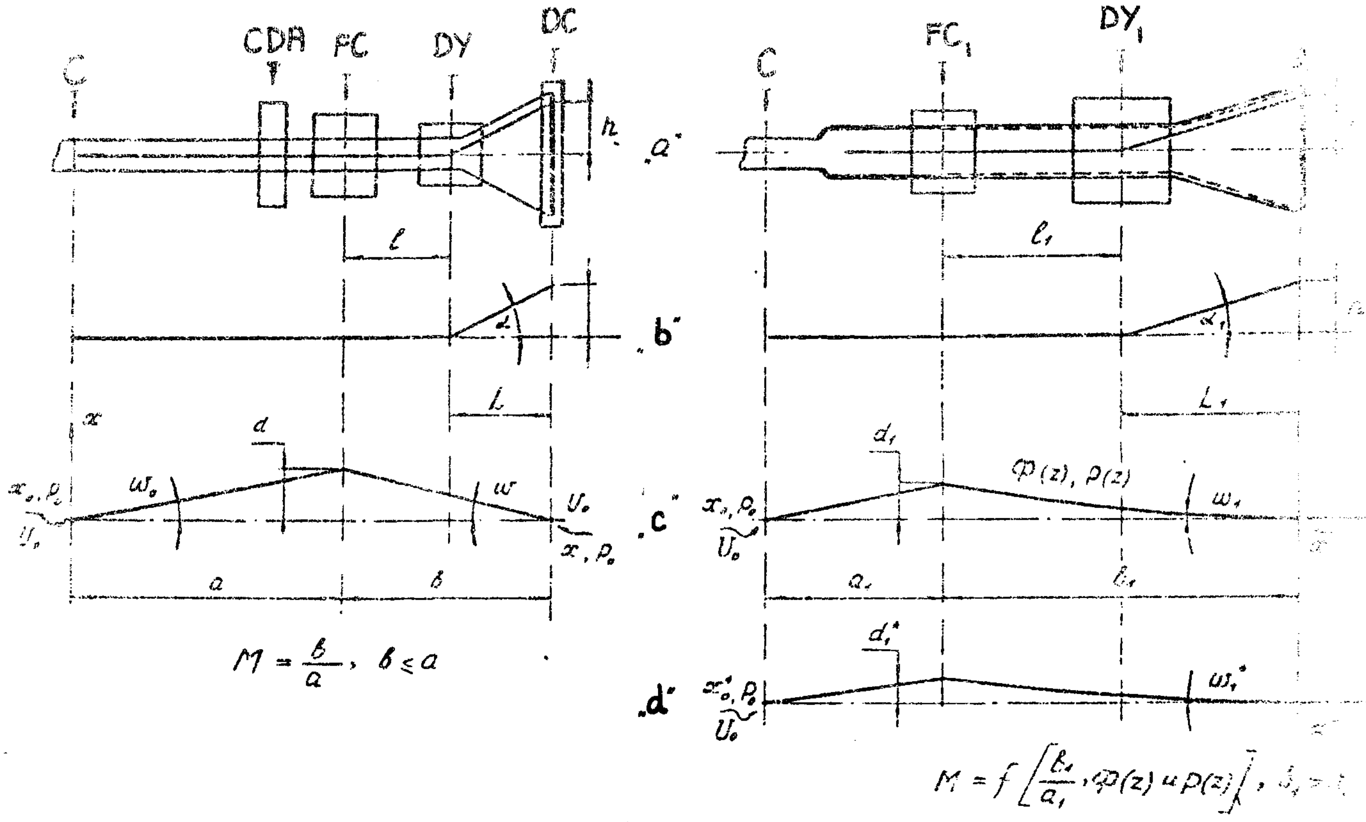

Fig. 1.

Layout of a CRT unit with a triode (tetrode) gun - left-hand diagram.
Layout of a CRT unit with a triode (tetrode) gun and "high-voltage compression" of the electron beam - right-hand diagram.

Key:
- a) General layout of a CRT unit with the magnetic control elements:
  - C - position of the crossover (second crossover for tetrode guns),
  - DY and DY_1 - deflection yokes,
  - FC - coil of the main focussing lens, also containing the static astigmatism correction and the dynamic focus-correction coils,
  - FC_1 - coil of the main focussing lens with a static astigmatism correction coil,
  - CDA - coil providing dynamic correction for astigmatism (diquadrupole lens),
  - DC - coil for correcting geometrical distortions (octupole lens);
- b) Deflection coil;
- c) Electron-optical focussing system;
  - M - magnification factor
- d) Electron-optical focussing system for the compressed electron beam.

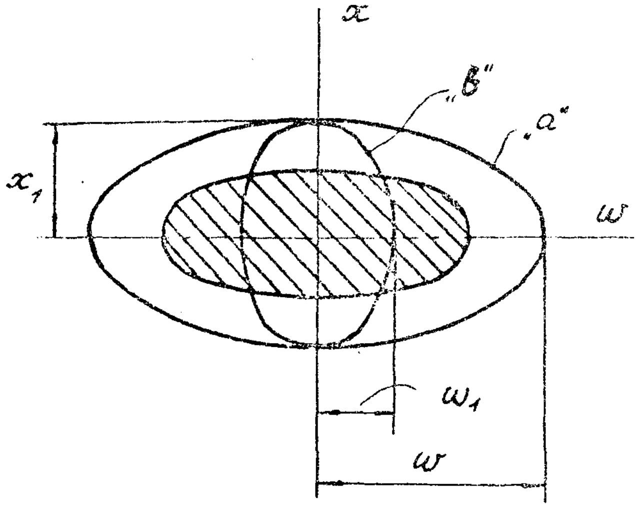

Fig. 2. Ellipses on the phase plane illustrating the Helmholtz equation.

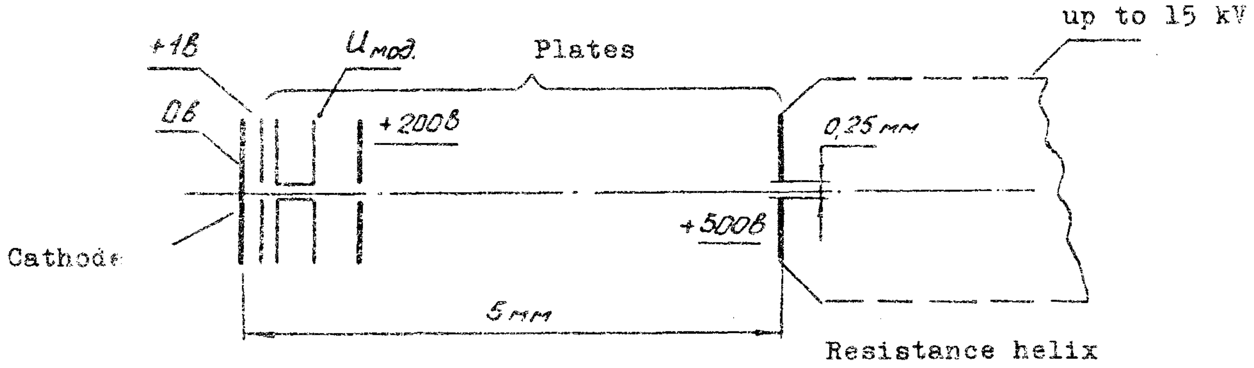

Fig. 3. Electron gun with a quasilaminar beam.

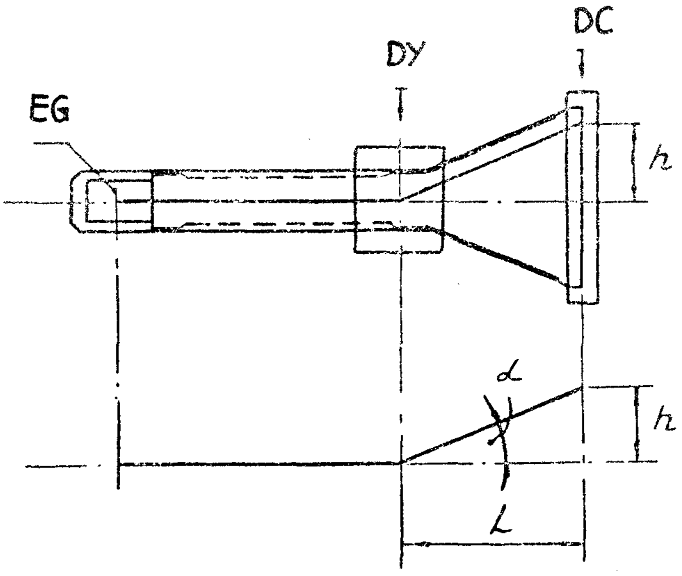

Fig. 4. Layout of a CRT terminal with a quasilaminar beam:
EG - electron gun;
DY - deflection yoke;
DC - coil for correcting distortion.